U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

SEISMICITY MAPS OF THE SANTA ROSA 1° × 2° QUADRANGLE, CALIFORNIA FOR THE PERIOD 1969-1995

by

Jeroen S. Preiss, Stephen R. Walter, and David H. Oppenheimer

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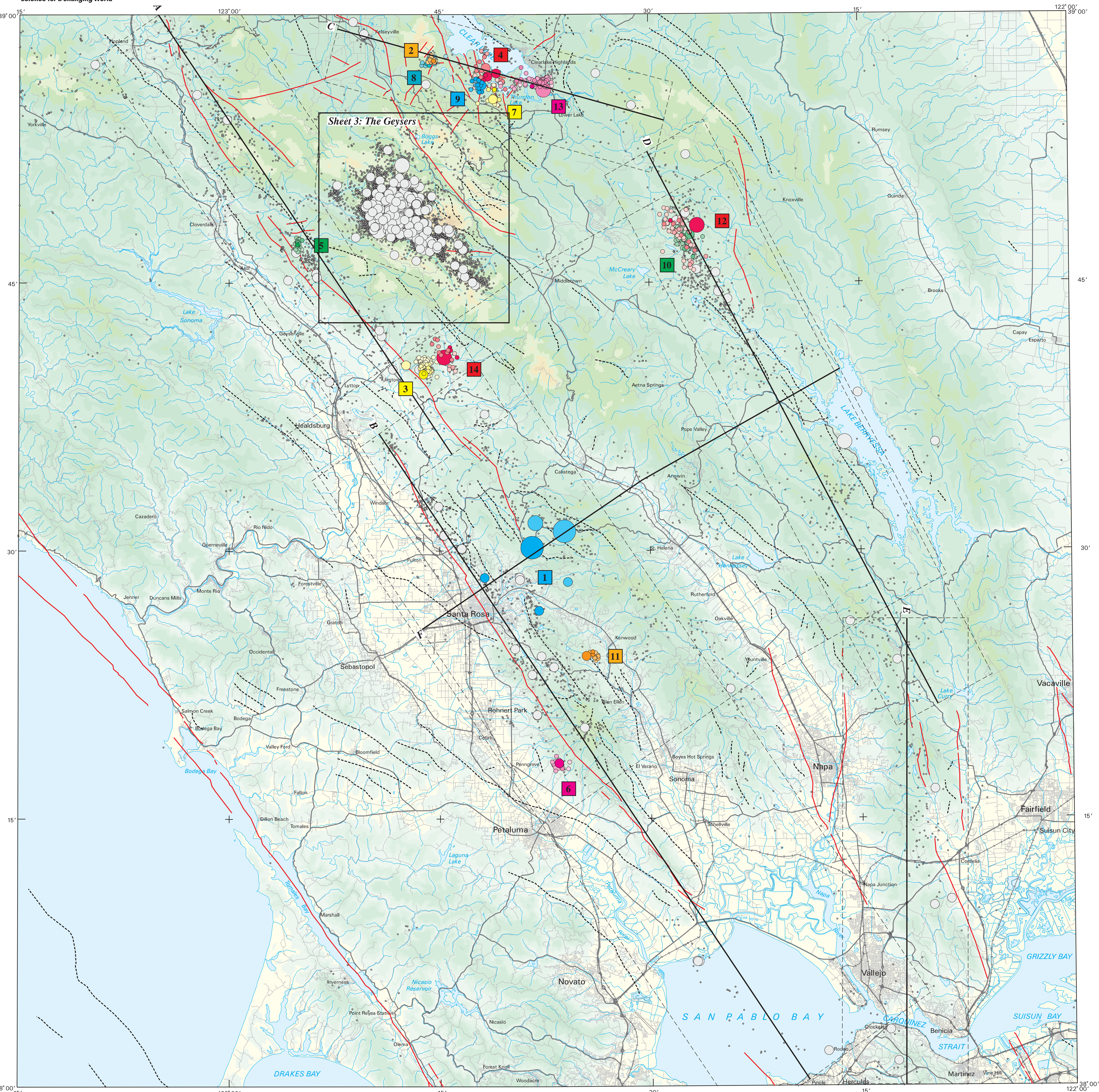


Topography from Defense Mapping Agency 1:250,000-scale Digital Elevation Model (DEM): Santa Rosa (east, west), 1987

Roads and hydrography from U.S. Geological Survey 1:100,000-scale Digital Line Graphs (DLG): Point Arena, 1981; Healdsburg, 1972; Bodega Bay, 1982; Napa, 1983

Geographic names from U.S. Geological Survey 1:100,000-scale published maps: Point Arena, 1981; Healdsburg, 1972; Bodega Bay, 1982; Napa, 1983

Transverse Mercator projection. Longitude of central meridian: 123°W.

SCALE 1:250 000

ELEVATION IN METERS

MAP B - SIGNIFICANT EARTHQUAKE CLUSTERS

PRESENTATION OF EARTHQUAKE CLUSTERS

The information presented on sheet 2 illustrates the same data presented on sheet 1, but the colored symbols depict individual earthquake sequences that are clustered in space and time. The calculation of the earthquake clusters is based on the method of Reasenberg (1985), which assigns an earthquake to a cluster using magnitude-dependent spatial and temporal relations. Except for earthquakes at The Geysers, we show only those clusters with at least 15 events and clusters with fewer events if it includes an earthquake with $M > 4.5$.

A number enclosed by a colored square on map B designates the cluster number (table 1). The color of the square corresponds to the color of the nearby earthquakes that belong to the cluster. Different clusters that are widely separated may have the same color. We decrease the color saturation of each color as the logarithm of time elapsed since onset of seismicity, in order to represent the time behavior of each cluster (see table 1). Only 1 percent of the earthquakes in map B are associated with clusters; the remaining events are shown in grey.

The number of events per cluster is a function of the data selection criteria discussed on sheet 1 and the cluster method. As an example of the latter, about 15 earthquakes occur at The Geysers geothermal field each day, but they rarely occur as foreshock-aftershock sequences. Because of this behavior, the clustering algorithm identified almost the entire twenty years of seismicity at The Geysers as belonging to a single cluster. We have chosen to portray The Geysers seismicity on map B as unclustered (grey), and instead present its temporal behavior on sheet 3 in a manner that relates the time of earthquake occurrence to the chronology of geothermal production.

Earthquake clusters commonly occur as mainshock/aftershock sequences, such as the 1995 Knights Valley sequence (cluster 14). However, some clusters in this region have no obvious mainshock and occur in short swarms, like the 1985 Thurston Lake swarm (cluster 9). As mentioned on sheet 1, there were few seismic stations available to record the 1969 Santa Rosa sequence (cluster 1). Consequently, the 5 events in this cluster are undoubtedly far fewer than would have been recorded with the seismic stations now installed in this region. As also discussed on sheet 1, the locations for this particular cluster are very uncertain, and the accuracy of the information cluster 1 in cross-section F is probably not reliable.

CROSS SECTIONS

Cross sections on sheet 2 depict the same seismicity shown on map B, but the scale is enlarged to 1:100,000 to reveal details of seismicity. Cross sections of The Geysers seismicity are shown on sheet 3, but portrayed in a slightly different manner. The depth of each earthquake computed by Hypoinverse (Klein, 1989) is relative to the mean elevation of the seismic stations that were used to locate the earthquake; depth is not relative to sea level. In this region the median station elevation is 0.3 km, but station elevations range from near sea level to 1.7 km. The distance scale on the cross sections is in kilometers. Each cross section, shown as a solid line on map B, depicts data selected from a corresponding polygonal area outlined by dashed lines. We depart from the usual convention of labeling cross sections at both ends to avoid obscuring earthquake symbols on the map. Instead, the labels are shown only on the left end of the solid line bisecting each polygon on map B and only at the upper left corner of each cross section. The labeled dashed lines above the cross sections indicate the width of intersecting cross sections. These dashed lines are terminated with an arrow and vertical line unless the intersecting cross section extends beyond the section.

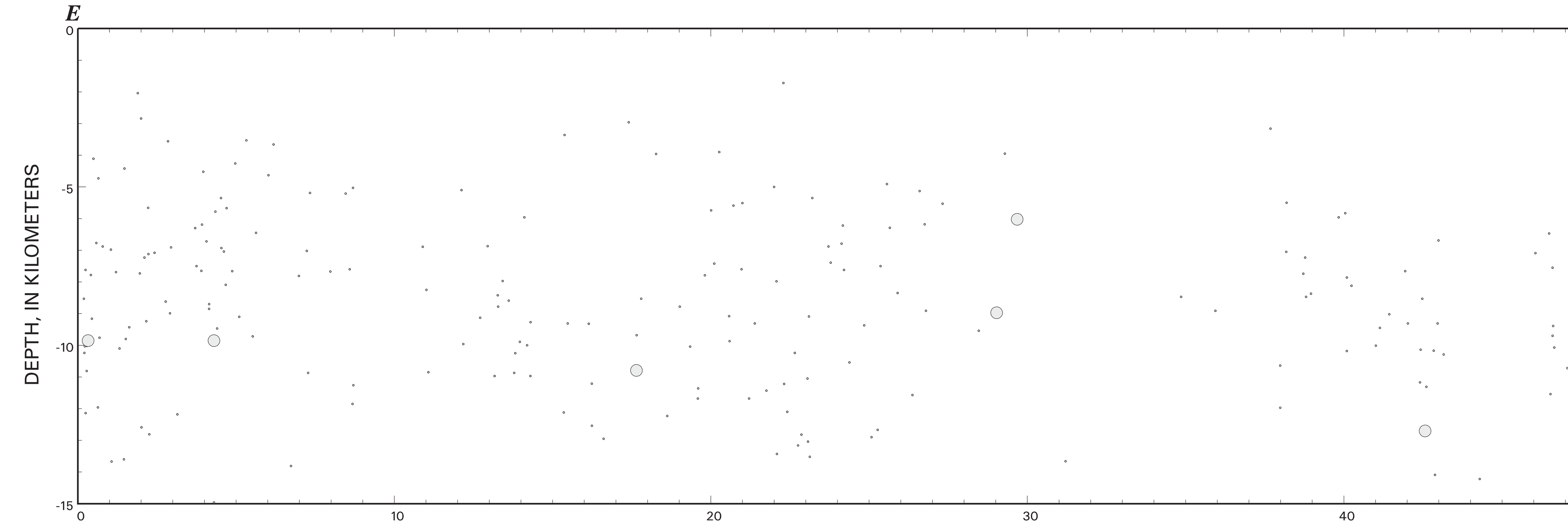
Locations of significant faults mapped at the Earth's surface are shown above the cross sections (fig. 2). As discussed on sheet 1, the earthquake hypocenters may be systematically mislocated because of three-dimensional variations in velocity not fully modeled by the location procedure. These mislocations may be manifest as an offset of the seismicity from the surface fault trace and by modest dips in the alignment of seismicity on faults that may be vertical. Discrepancies between the fault dips imaged in these cross sections and the dips of the focal mechanisms shown on map A may also indicate regions where earthquakes are systematically mislocated.

In some areas where the seismicity does not clearly resolve the subsurface fault structure, the hypocentral location uncertainty is much less than the apparent scatter in earthquakes (except for cluster 1). For example, the diffuse seismicity where the Rodgers Creek - Healdsburg faults overlap with the Maacama fault occurs in a region nearly 15 km wide. These earthquakes occur on small, unorganized faults. Further examination of cross-section F shows that some individual clusters (6, 11, and 14) occur on discrete, near-vertical faults. The latter provide additional confirmation that the diffuse seismicity is not a mislocation artifact.

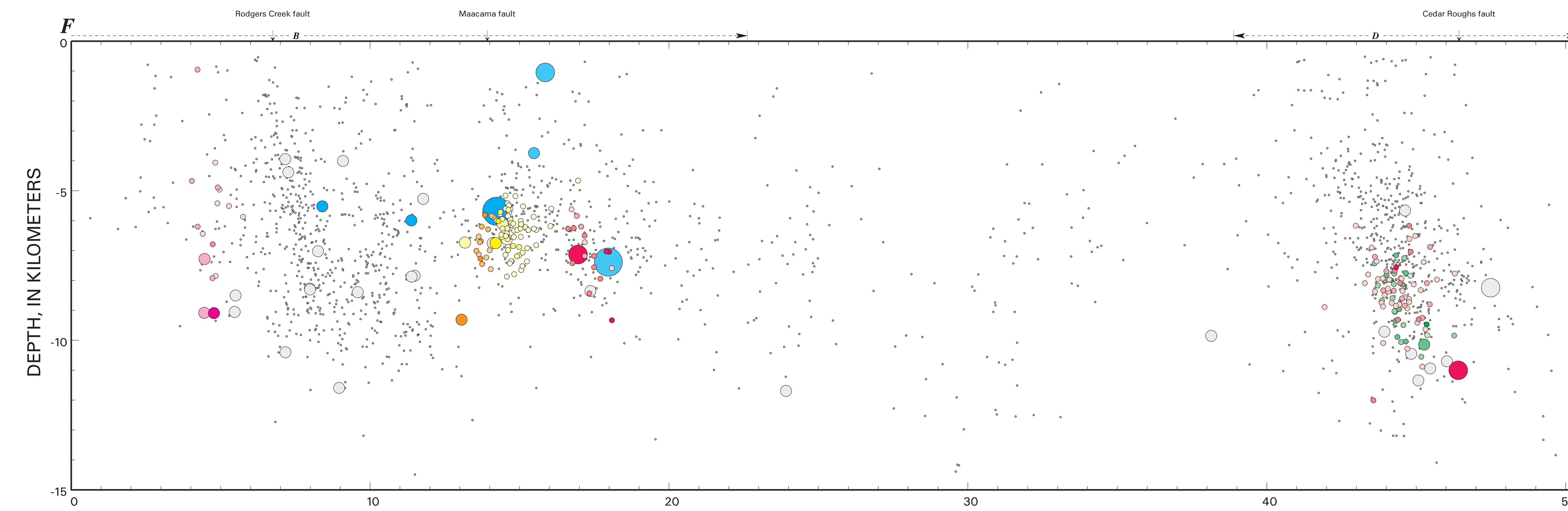
In general, seismicity extends to depths of about 13 km along most active faults in this region. However, in The Geysers region (sheet 3) and in the region immediately south of Clear Lake most earthquakes occur at depths less than 6 km. This shallow seismicity may be related to the high heat flow of the Clear Lake region, which has experienced eruptions of the Quaternary Clear Lake Volcanics as recently as 10,000 years ago (McLaughlin and Donnelly-Nolan, 1981).

Cross section B shows that during the time interval 1969-1995 few earthquakes occurred on the Rodgers Creek fault from Sonoma Mountain (cluster #6) south to San Pablo Bay. Moreover, much of the seismicity along the Rodgers Creek fault between Sonoma Mountain north to Santa Rosa likely occurs off the fault. Budding and others (1991) discuss the extent of this seismic gap in the context of the historical seismicity, creep, and slip rate of the Rodgers Creek fault. They conclude that the Rodgers Creek fault is capable of rupturing in a $M7$ earthquake and that the minimum elapsed time since the last event (182 years) approaches the maximum recurrence interval of 248-679 years. Map A shows a similar absence of seismicity along the San Andreas fault, which ruptured in the $M7.9$ 1906 quake, but the seismic hazard for this fault is relatively low because estimates of the recurrence interval for the north coast segment of the San Andreas fault exceeds 200 years (Dieterich *et al.*, 1990).

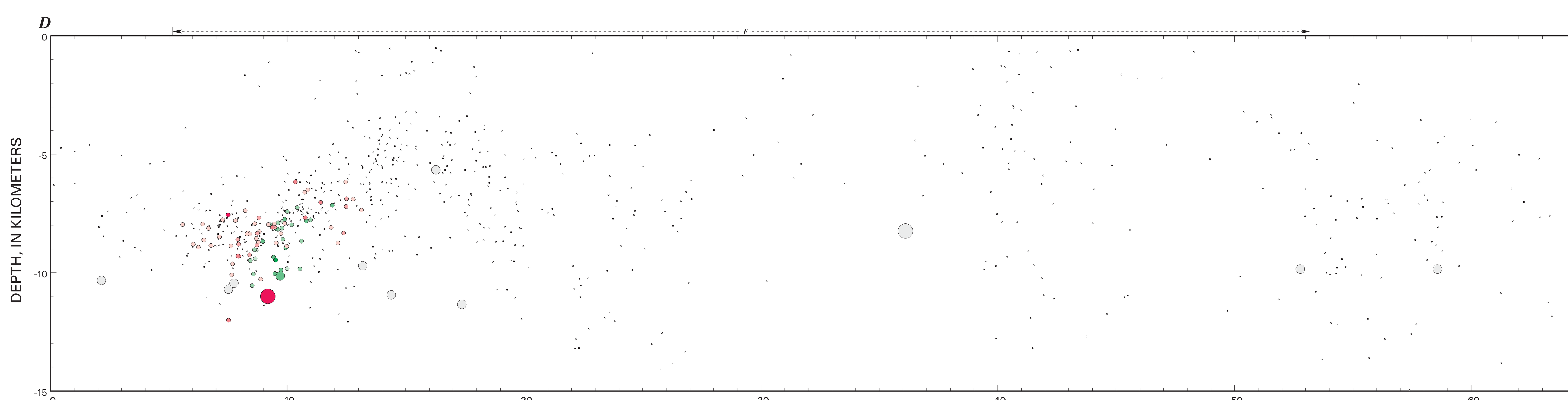
E



F



D



EXPLANATION

Clustered earthquakes are shown as colored symbols, the color fading with time after the first event (table1). Unclustered earthquakes are gray, except for M<3.0 earthquakes that are shown as very small open circles.

Magnitude

0.0 - 2.9 **3.0 - 3.9** **4.0 - 4.9** **5.0 - 5.9** **6.0 - 6.9** **7.0 +**

1 **Cluster -** See table 1. Color of square corresponds to color of nearby earthquakes that are included in the cluster

B **Cross section -** Sections are shown at 1:100,000 scale. Dashed box encloses earthquakes plotted on cross section

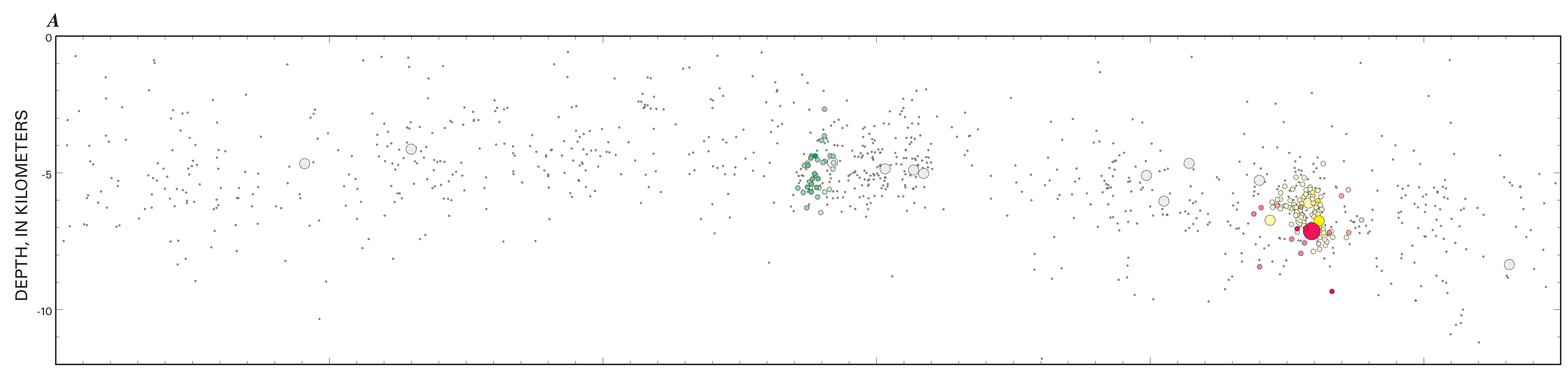
Faults

(Fault traces were digitized at 1:750,000 (Jennings, 1994) and may be mislocated by as much as 0.8 km (0.5 mi) when plotted on this map at 1:250,000. Fault traces are not intended for engineering or land-use purposes.)

Late Quaternary (displacement <700,000 yr)

Early Quaternary (displacement <1,600,000 yr)

A



C

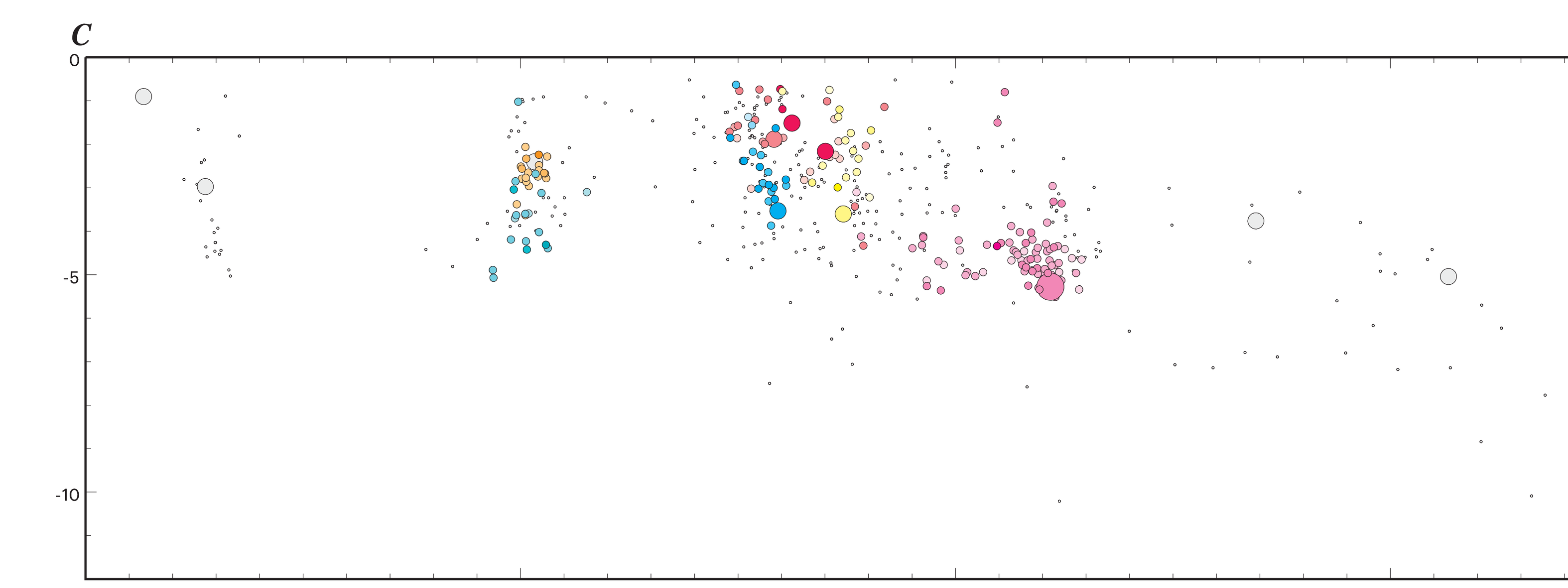
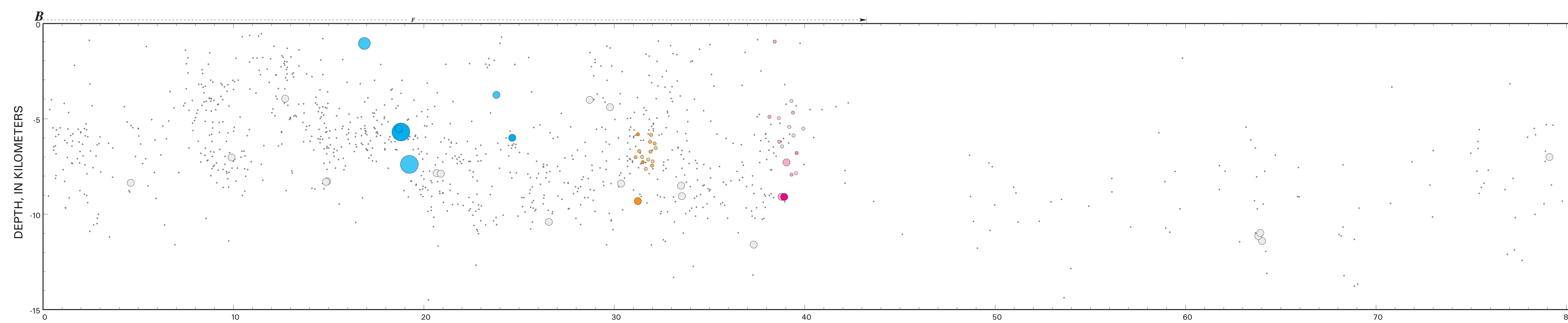


Table 1. *Significant earthquake clusters from 1967-1995 shown on map B and cross sections*

Cluster number	Geographic location	Start date (yr/mo/dy)	Main event magnitude	Number of events	Duration (days)	Time after first event (hours) 0 - 0.9	1 - 9.9	10 - 99.9	100 - 999	>999
1	Santa Rosa	69/10/02	5.7	5	<1	●	●			
2	Mt. Konocti	75/09/29	2.6	19	2	●	●	●		
3	Jimtown	77/09/08	3.8	74	44	●	●	●	●	●
4	Thurston Lake	80/12/12	3.9	47	12	●	●	●	●	
5	Caslamayomi	81/12/02	2.8	33	18	●	●	●	●	
6	Sonoma Mt.	81/12/18	3.1	19	23	●	●	●	●	
7	Thurston Lake	82/08/04	3.0	16	17	●	●	●	●	
8	Mt. Konocti	83/06/19	2.5	18	9	●	●	●	●	
9	Thurston Lake	85/03/06	3.5	23	5	●	●	●	●	
10	Putah Creek	86/12/14	3.3	30	17	●	●	●	●	
11	Kenwood	93/11/08	3.5	15	3	●	●	●		
12	Jerusalem Vly.	94/01/17	4.1	55	33	●	●	●	●	
13	Lower Lake	95/02/28	4.0	78	10	●	●	●	●	
14	Knights Valley	95/09/04	4.6	18	15	●	●	●	●	

B



The publication also includes digital versions of the map sheets, which are available on the World Wide Web at: http://geopubs.wr.usgs.gov/open-file/of02-209.